Emissions trading under market imperfections

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ACADEMIC DISSERTATION

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Abstract

In this thesis we consider emissions trading under various market imperfections such as uncertainty over permit price, imperfect competition and noncompliance. First, we study the effects of uncertain permit price on the firms choice of emission intensive and clean inputs in an multi-input production process. We also assess the risk aversion factors of some Finnish heat and power producers. Second, we study imperfect competition in output and permit markets with a two-stage model, where output decision is made before permit trades. The emphasis is on the strategic interaction between firms and on the efficiency increasing regulation. Third, we turn back to uncertainty and analyse the welfare difference between emissions trading and emission tax, when some of the firms may be noncompliant. The main finding is that welfare is greater with emission tax than with emissions trading, when at least one firm is noncompliant. Finally, we extend some existing models of permit banking and borrowing to encompass also noncompliant behavior of firms. Here, we analyse the incentives of compliant firms to become noncompliant at some point in time and also the time paths of the choice variables.

Keywords: Emissions trading; emission tax; uncertainty; mean-variance analysis; market power; duopoly; regulation; compliance; monitoring and enforcement; welfare; banking; intertemporal choice.

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List of original articles

1. Lappi P., Ollikainen M., Ollikka K. (2010) Optimal fuel-mix in CHP plants under a stochastic permit price: Risk-neutrality versus risk-aversion. Energy Policy 38: 1079–1086

2. Lappi P. (2012) Duopolists in output and permit markets: Interaction and regulation. Strategic Behavior and the Environment 2: 279–293

3. Lappi P. (2013) Emissions trading versus emission tax under noncompliance: welfare comparison. Submitted

4. Lappi P. (2013) Emissions trading, noncompliance and bankable permits. Submitted

Contents

1 Introduction

Emissions trading is based on a simple but insightful idea. A cap is imposed by the regulator on the industry's emissions, which is distributed among firms as permits. The firms are then allowed to trade these permits among themselves. This means that the firms decide how much each of them abates, instead of regulator deciding their abatement levels. Montgomery (1972) was the first to demonstrate that emissions trading is a cost-efficient instrument to control global uniformly mixed pollutants.[1] Since the first modest applications of emissions trading the number of emissions trading programs on airborne emissions and water quality has been growing rapidly.

Cost-efficiency is one of the key reasons why countries have adopted emissions trading. Most recently, emissions trading is used as a climate change mitigation policy in the form of the European Union Emissions Trading System (EU-ETS). The observed features of the existing programs have raised the question whether the cost-efficiency property actually holds or not. Therefore, one needs to examine the assumptions behind efficient emissions trading market and cost-efficient emission reduction. This amounts to studying the role of various market imperfections. To put it briefly, this thesis studies the effect of different market imperfections on emissions trading market.

I begin my discussion with the cost-efficiency property of emissions trading and the main assumptions behind it. The given emissions cap is achieved in a cost-efficient way, when the polluting firms choose their emissions such that marginal abatement costs are equalized across firms. The assumptions on the emissions trading market include: the participating firms are price takers in all relevant markets such as permit, output and input markets; the firms operate under certainty; the firms are compliant and there are no transaction costs related to permit trades. Under these assumptions, firms choose

[1] For cost-efficiency see Baumol and Oates (1988).

their emissions such that the permit price equals the marginal abatement costs, implying that marginal abatement costs are equalized among firms. Because of this, we say that emissions trading is a cost-effective instrument to control pollution. An important feature of emissions trading is that the initial allocation of permits has no effect on the equilibrium choices of the firms. Note that under the above assumptions also emission tax is cost-efficient.

The main theme of this thesis is to reconsider the basic emission trading model: I examine the effects of permit price uncertainty, market power and noncompliance on the efficiency properties of emissions trading. I next survey the most important studies on these topics, and present typical models from the literature and discuss questions waiting for further study.

2 Related literature

2.1 Price uncertainty

The theory of the firm has typically examined the impact of uncertainty showing up in the output price or in the input prices. The seminal contribution is Sandmo (1971) who models a competitive firm under output price uncertainty. His most important result is that the optimal output of a risk-averse firm under uncertainty is smaller than (or equal to) the output, when output price is equal to its expected value. Similar result is obtained by Ben-David et al. (2000) in the context of emissions trading: they assume that the permit price is uncertain and find that abatement levels differ from the ones where the permit price equals its expected value. This has an important implication: cost-efficiency property of emissions trading may not hold anymore. This result can be derived for example with the following model. Assume that the permit price is uncertain and that the problem of the firm is to

$$\max_{\{e\}} \mathbb{E}U\left(\pi(e) - \hat{p}(e - e^0)\right), \quad \text{s.t.} \quad e \geq 0, \tag{1}$$

where e are the emissions of the firm acting as the choice variable, $\mathbb{E}$ is the expectation operator and U is the utility function. The function π is the benefit function of emissions and it is usually assumed to be strictly increasing and strictly concave in emissions. The parameters $\hat{p}$ and e^0 are the uncertain permit price and the initial allocation of permits for the firm, respectively. With this model it can be shown that at an interior optimum the marginal abatement costs differ from the expected permit price for a risk-averse permit seller or buyer.

In the above models there are no forward markets and therefore in Sandmo's model risk aversion affects the choice of output (or the choice of abatement in Ben-David et al.). However, as shown by Holthausen (1979), if a firm under output price uncertainty is allowed to write forward contracts, risk aversion affects only the amount of output hedged, not the amount of output produced. In this sense, the production decisions and the financial decisions are separated.

An important paper from the viewpoint of the thesis is Blair (1974). He considers the choice of inputs when input prices are uncertain, and finds that risk-averse firm uses less each risky input compared to that of a risk-neutral firm. This result follows because the marginal cost of an input is affected by uncertainty and by the firm's risk attitude.[2]

The issue of permit price uncertainty is important also in practice. This is so in particular in the EU-ETS. For example Blair's result may change in an emissions trading model, since input use may depend on the position of the firm in the permit market either as a buyer or a seller. Also, the literature related to emissions trading is short

[2] A significant paper related to emissions trading under uncertainty is Baldursson and von der Fehr (2004). In addition to the effects on the optimal choices of the firms, uncertainty is relevant also for the choice of environmental policy instruments in general. This is discussed in the so-called prices versus quantities–literature started by Weitzman (1974) and continued by Stavins (1996) among others.

of the studies about forward trading, and Holthausen's conclusions have not yet been studied in this context.

2.2 Market power

Market power can be a problem for example in the output market or in the permit market. The models in the literature are often based on a dominant firm-competitive fringe setting, where one or more firms have a dominant position for example in the permit market and are thus able to influence the market price of permits. The firms who are in the competitive fringe act as price takers. Market power in the output market is typically modelled either as monopoly or as Cournot competition.

For concreteness, consider a permit market with two dominant firms, firm 1 and firm 2, and a competitive fringe. Assume furthermore that the dominant firms are Cournot competitors in the output market, and that the fringe firms behave competitively in their own output market. This situation can be modelled as follows. The dominant firms have first mover advantage and therefore take the optimal choice of the fringe as given. The objective function for one of the dominant firms, say firm 1, is

$$P(x_1 + x_2)x_1 - C_1(x_1, e_1) - p(e_1 + e_2)(e_1 - e_1^0), \tag{2}$$

where the choice variables are output x_1 and emissions e_1. The inverse demand function for the output is P, the cost function is C_1, and the permit supply function is p. The parameter e_1^0 is the initial allocation of permits for firm 1.

This model encompasses several of the most important contributions in the literature.[3] For example, suppose that there is a single dominant firm in the permit market, who is a price taker in the output market. For this case Hahn (1984) showed that the initial allocation of permits matters for the cost-efficiency of emissions trading, and emphasized

[3]See Montero (2009) for a more detailed review of the literature related to market power, and Requate (2005) for a review related to market power and environmental policy instruments in general.

that the inefficiency due to market power grows with the distance between the initial permit allocation and the permit need of the dominant firm.[4]

When market power is introduced also to the output market new issues arise in the role of strategic interaction. The first step to this direction is Misiolek and Elder (1989). They let one of the firms to be able to influence the permit price and also the output price. They show that in this case the dominant firm may manipulate the permit market in order to drive the rival's costs up, thus gaining a higher market share in the output market. The duopoly setting (2) is, among other things, studied by von der Fehr (1993) with a two-stage model, where the firms use emissions as a strategic variable to influence the competition in the output market. One interesting result is that the firms overinvest in permits relative to competitive level. Other studies related to market power are Eshel (2005) and Sartzetakis (1997). Eshel studies the optimal allocation of permits and Sartzetakis carries out a welfare comparison between tradable and non-tradable permits under market power only in output market.

In practise policy makers and researchers have been interested in the effects of market power. For example, market power in both output and permits markets is a real concern in the EU-ETS (Hintermann 2011). These worries demand further research, in particular, related to strategic interaction between firms.

2.3 Noncompliance

Emissions trading and also other policy instruments such as emission tax must be enforced and monitored properly to yield the desired outcomes.[5] If firms' emissions cannot be measured accurately, the firms may either try to find ways to cover up their actual

[4]Recent contributions to the literature on market power in permit markets are Malueg and Yates (2009) and Lange (2012), who allow every firm to have market power. This is important, since in the discussed modelling framework the firms are divided by the modeller to ones that have market power and to the ones that do not (Lange 2012).

[5]The seminal contributions in this strand of the literature include Hartford (1978, 1987).

emissions or, if required to self-report their emissions to the regulator, underreport their emissions. In either case it can be expected that the cost-efficiency property fails. The regulator may audit firms and sanction penalties for underreporting, but since auditing is expensive, not all firms will be audited (or found guilty of underreporting). Therefore the choice of emissions is made under uncertainty concerning auditing and the risk attitudes of the firms may play a role, although risk-neutrality has been a common assumption in the literature. Besides assumptions regarding risk attitudes of the firms, an important modelling choice is related to the probability of auditing. There are basically two options for the modeller: either the regulator knows (or sets) the probability of auditing that the firms employ, or not.[6]

As an example, the maximization problem for a risk-neutral firm can be stated as

$$\max_{\{e,\hat{e}\}} \{-C(e) - p(\hat{e} - e^0) - S(v)\}, \quad \text{s.t.} \quad e \geq 0,\ \hat{e} \geq 0,\ v \geq 0, \tag{3}$$

where e denotes the actual emissions and $\hat{e}$ denotes the reported emissions. The violation v is defined as $e - \hat{e}$. The cost function is C. The function S is the expected penalty function defined as the product of the auditing probability and the penalty function set by the regulator. This problem can be regarded as a simplification of the model in Malik (1990), who was the first to study monitoring and enforcement issues in emissions trading. Malik's important finding is that the cost-efficiency condition no longer holds. Other studies related to emissions trading are Keeler (1991), Malik (1992, 2002), van Egteren and Weber (1996), Stranlund and Dhanda (1999), Montero (2002) and Arguedas et al. (2010). The literature on noncompliance contains only one study, Montero (2002), where the welfare difference between emissions trading and emission tax are studied under

[6]The case where the regulator knows the probability can be named as objective probability (for example Stranlund 2007). In the other case, where the regulator does not know the probability firms employ in their optimization we say that the probability is subjective. Note that although a certain fraction of firms are audited, a particular firm may think that its choices, such as the level of violation, affects the chance of the firm belonging to the set of audited firms. In this sense, the regulator does not know the probability the firms thinks it gets audited.

noncompliance. Montero finds that both instruments yield the same welfare if the cost and benefit functions are known with certainty.

2.4 Banking

Many emissions trading programs in practise allow firms to bank permits for future use and/or to borrow permits from the future endowments for current use. For instance, in the EU-ETS banking is allowed but so is borrowing, because the permits of a given year must be handed over after the date when next year's allocation is received (Chevallier 2012). This essentially means that borrowing is allowed at least to some extent in the EU-ETS. Also, in the United States the American Power Act allows participants to bank and borrow permits, although an interest must be paid for the borrowed permits and the borrowing of permits is limited (Leard 2013).

The added benefit of permit banking and borrowing is to allow firms to reach cost savings by adjusting the time paths of emissions. One of the first papers to study banking are Cronshaw and Kruse (1996), Rubin (1996), Kling and Rubin (1997) and Schennach (2000). As for the example model of banking and borrowing we follow Rubin (1996): a firm that is allowed to bank and borrow permits maximizes the discounted value of the benefits from emissions over the planning interval $[0, T]$.[7] The problem is therefore to

$$\max_{\{e(t),x(t)\}} \int_0^T e^{-\rho t} \left[-C(e(t)) - p(t)x(t)\right] \, \mathrm{d}t \tag{4}$$

$$\text{s.t} \quad \dot{B}(t) = e^0(t) + x(t) - e(t), \quad B(0) = 0, \quad B(T) \geq 0, \tag{5}$$

$$- x^{min} \leq x(t) \leq x^{max}, \quad e(t) \geq 0. \tag{6}$$

Here the firm chooses the time paths of emissions $e(t)$ and permit trades $x(t)$. Parameter ρ is the discount rate. The differential equation in (5) is the state equation describing the change of the number of permits in the bank account B at time t. Furthermore there

[7] See Xepapadeas (1997) for the design of environmental policy under stock externalities.

are bounds for the control variables x and e that are given in (6). Using a similar model Rubin shows that the firms choices result in at most the cost as would result when the regulator solves the total-cost minimization problem with full-knowledge of the firms' cost functions. He also studies the time path of emissions.

Although permit banking is not a market imperfection as such, all of the market imperfections considered so far are relevant also when banking is allowed. For example, Liski and Montero (2005) use a model of dominant firm with a competitive fringe to analyse the effects of market power, when firms are allowed to bank permits. However, from the viewpoint of this thesis the models related to noncompliance and banking are the most interesting ones. This type of analysis is conducted only in one paper, Stranlund et al. (2005). They analyse the design of monitoring and enforcement that results in full compliance, and find among other things that constant penalties can be used for this. In article 4, discussed shortly in subsection 3.4, we extend the results of Rubin (1996) and Stranlund et al. (2005) by allowing the firms to be noncompliant and to bank permits.

3 Summaries of the articles

3.1 Article 1. Lappi, Ollikainen and Ollikka: Optimal fuel-mix in CHP plants under a stochastic permit price: Risk-neutrality versus risk-aversion

We consider the input choice of a risk-averse combined heat and power (CHP) producer operating under permit price risk. We use a mean-variance framework to analyse the consequences of changes in expected permit price and in variance of the permit price on the choice of three fuels of which two are CO_2-intensive and one is clean. We develop two models. In the first one the producer is only allowed to make spot-trades in the permit market, and in the second one the producer also has the option to make forward-trades.

We find in the spot-model the expected results that an increase in the expected permit price increases the use of the clean fuel. Also, an increase in the variance of the permit price increases the use of the clean fuel, when the producer is a buyer of permits, and decrease the use, when the producer is a seller. This is intuitive since a risk-averse permit buyer can decrease the need to buy permits in a risky price by using more clean fuel. In the forward-model we essentially derive the well-known separation property of production and financial decisions under uncertainty, which was discussed in subsection 2.1. This property means in this context that the fuel use depends only on the certain fuel unit price and on the forward price of permits. In this case the risk aversion, price risk and the initial allocation of permits affect only the amount of permits hedged.

The policy implication of these results is that for the emissions trading program to be cost-efficient, the forward markets for permits must be operational and the producers must have access to them. Otherwise, the initial allocation of permits affects the optimal choice of fuels. We also use the model to estimate the size of the risk-aversion coefficients for Finnish CHP-producers. With a simple econometric exercise we found that risk neutrality suits the producer behavior better than risk aversion.

3.2 Article 2. Lappi: Duopolists in output and permit markets: Interaction and regulation

We study firm behaviour in imperfectly competitive permit and output market using a two-stage duopoly setting similar to von der Fehr (1993). The differentiating feature is that the stages are inverses relative to von der Fehr, namely, we assume that the choice of permits is conditional on the output choice. Therefore output acts as the strategic variable. It seems plausible that this order of moves is more relevant to some of the current emissions trading programs such as EU-ETS.

We show that the total output is greater when the firms are able to influence the outcomes in both of the markets as permit buyers compared to the case where permit markets is competitive but output market is not. When the firms are permit sellers the opposite result is obtained, that is, the total output contracts.

In addition to the effects of strategic interaction we analyse possible regulation to counteract the negative effects of imperfect competition.[8] When the duopolists are permit buyers, they buy fewer permits compared to competitive markets. Therefore it seems reasonable that a subsidy for permit buying may increase efficiency. This is exactly the case as shown in the paper. If the duopolists act as permit sellers, then a tax increases efficiency. In both cases the regulation is designed to induce cost-efficient abatement, which is not itself sufficient to increase efficiency since the effect on output markets needs to be taken into account. However, as shown in the paper, total output is greater with regulation than without it.

[8]The regulation is an adaptation of the tax/subsidy scheme presented in Kim and Chang (1993).

3.3 Article 3. Lappi: Emissions trading versus emission tax under noncompliance: welfare comparison

We perform a welfare comparison between emissions trading and emission tax under the assumption that the firms must self-report their emissions to the regulator. In effect, some of the firms may be noncompliant. This is important since some of the trading programs have achieved full complaince but some have not (Chan et al. 2012, Montero et al. 2002). The main result of the study is that welfare under emissions trading is at most the welfare under emission tax; the welfare is the same only when all firms are compliant.

To reach this conclusion we first show the intuitive and well-known results that the equilibrium permit price is increasing in the number of compliant firms and that actual emissions of a firm are greater when it is noncompliant than compliant. Under emission tax the actual emissions are the same irrespective to the compliance status of the firm. It is then shown that the main conlusion of the paper follows from these observations assuming that the instruments are set to their first-best levels. The key elements used are that the equilibrium permit price is not greater than the tax, and that actual emissions differ between instruments.

This result is in sharp contrast to the result obtained by Montero (2002), who found that the instruments yield the same welfare (under certainty). Although the modelling approaches are quite different, the divergent results may follow from the assumptions regarding the auditing probability function. Montero assumes that this probability is constant and set by the regulator, but we assume, that the probability is subjective and nonlinear in violation, and cannot therefore be set by the regulator.[9]

[9] The assumption that the probability of auditing depends on the level of violation, which the regulator does not directly observe, is often employed in the literature (for example Arguedas et al. (2010), Malik (2002), van Egteren and Weber (1996) and Rousseau and Proost (2005)). The rationale to condition this probability to something that the regulator does not observe is that the regulator receives a noisy signal of the violation (Rousseau and Proost 2005), which can be for example high level of output but low level of reported emissions.

Since noncompliance yields lower tax revenues for the regulator, we also conduct a brief study of a model where the regulator sets the tax or the initial allocation of permits to be auctioned under budget constraint.

3.4 Article 4. Lappi: Emissions trading, noncompliance and bankable permits

We combine two strands of literature, noncompliance and banking literatures, to analyse the effects of noncompliance in an emissions trading system, where the participants are allowed to bank and borrow permits. Similarly to the model in the third article, we assume that the firms hold subjective views on the probability of auditing, and that the resulting expected penalty function is nonlinear. We also assume that firms must self-report their emissions to the regulator. The model in article 3 is static, but the analysis in this study is conducted in a dynamic framework using optimal control theory. The starting point of the model is therefore Rubin (1996), which we expand to analyze the effects of noncompliance.

The main contributions of the study are the characterization of the condition for noncompliance and the analysis of the time paths of actual emissions, reported emissions and violations. The condition for noncompliance is also studied in Stranlund et al. (2005), who use a discrete-time model and constant, objectively known penalties. Quite similarly to Stranlund et al. (2005) we find that full compliance can be achieved by pinning the expected marginal penalty to the going permit price. More exactly, we show that a firm is compliant if and only if the discounted expected marginal penalty at zero violation level is greater than equal to the permit price. But it may not be possible for the regulator to set the penalty function that produces full compliance simply because the auditing probability is subjective. Therefore it is important to study the effects of noncompliance on the time paths of actual and reported emissions.

To this end, the condition for noncompliance can be used. We show, that for a sufficiently long planning interval, at most two interesting instants of time exists. In the first the firm starts cheating, and in the second the reported emissions become zero and the actual emissions become constant. Additionally, actual and reported emissions are decreasing in time and violation level is increasing in time.

The results imply that some given penalty scheme may be efficient, in the sense that it implies full compliance, during some initial interval of time, but may turn out to be inefficient later on. Therefore the results have two messages for the regulator. It is a good idea to keep the planning interval short, if one only wants to induce full compliance. Also, if full compliance is desirable, make sure that the firms have little reason to form subjective probabilities over auditing, that is, make it clear that firms understand that a fixed proportion of them are going to be audited.

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